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# RESEARCH MEMORANDUM

## THE EFFECT OF TIP TANKS ON THE ROLLING CHARACTERISTICS AT HIGH SUBSONIC MACH NUMBERS OF A WING HAVING AN ASPECT RATIO OF 3 WITH QUARTER-CHORD LINE SWEPT BACK 35°


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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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# THE EFFECT OF TIP TANKS ON THE ROLLING CHARACTERISTICS AT HIGH SUBSONIC MACH NUMBERS OF A WING HAVING AN ASPECT RATIO OF 3 WITH QUARTER-CHORD LINE SWEPT BACK 35°

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## SUMMARY

An investigation of the effect of wing-tip mounted tanks on the rolling characteristics of a wing, aspect ratio 3 with the quarter-chord line swept back 35°, through the Mach number range from 0.4 to 0.91 and in the angle-of-attack range from 0° to 6.5° was conducted by the free-roll method.

Tanks suspended below the wing tips on sweptforward pylons caused only a small increase in the damping-in-roll coefficient and did not affect the aileron effectiveness. Tanks mounted directly on the tip caused an appreciable increase in both the aileron effectiveness and the damping-in-roll characteristics of the wing. The fairing used in the juncture between the tank and the wing also had an appreciable effect on both the aileron effectiveness and the damping-in-roll characteristics.

For the particular wing-aileron configuration used in this investigation, the effects of the various tank configurations on the damping-in-roll coefficient $C_{l_p}$ and the aileron-effectiveness parameter $C_{l_\delta}$ were such as to produce small and almost identical decreases in the rolling parameter $(pb/2V)_\delta$. The variation of the damping-in-roll parameter $C_{l_p}$ with Mach number, near zero angle of attack, was similar but somewhat greater than that of the wing alone for all configurations tested.

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## INTRODUCTION

The increasing use of auxiliary fuel tanks mounted at the wing tips of fighter aircraft has indicated the desirability of determining the effect of these tanks on the rolling characteristics of the airplane. Some experimental wind-tunnel work of this nature has been done on an unswept wing at low speeds (reference 1), but no experimental data are available to indicate the effect of compressibility on these characteristics.

The present investigation was undertaken to determine the effect of tip tanks on the damping-in-roll characteristics of a sweptback wing at high subsonic Mach numbers. Two different tank-mounting arrangements were investigated in the angle-of-attack range from 0.3° to 6.5° and in the Mach number range from 0.40 to 0.91. The effects of these tank configurations on the general aerodynamic characteristics are presented in reference 2. The damping-in-roll characteristics of this wing without tanks have been investigated previously and are presented in reference 3.

## COEFFICIENTS AND SYMBOLS

The data have been computed and presented with reference to the stability axis system.

| | |
|---|---|
| $a$ | speed of sound, feet per second |
| $b$ | wing span (3.093 ft on model) |
| $c'$ | mean aerodynamic chord (M.A.C.) (1.05 ft on model) |
| $c$ | wing chord, parallel to plane of symmetry |
| $C_l$ | rolling-moment coefficient (Rolling moment/qSb) |
| $C_{l_p}$ | damping-in-roll coefficient $\left(\partial C_l \middle/ \partial\frac{pb}{2V}\right)$ |
| $M$ | free-stream Mach number (V/a) |
| $p$ | rate of roll, radians per second |
| $q$ | dynamic pressure, pounds per square foot $\left(\rho V^2/2\right)$ |
| $R$ | Reynolds number $\left(\rho V c'/\mu\right)$ |

| | |
|---|---|
| S | wing area, (3.174 sq ft on model) |
| V | free-stream velocity, feet per second |
| $\rho$ | mass density of air, slugs per cubic foot |
| $\mu$ | absolute viscosity, pound-seconds per square foot |
| $\alpha$ | angle of attack, degrees |
| $\delta$ | control-surface deflection with reference to wing chord line parallel to plane of symmetry, degrees |
| $pb/2V$ | wing-tip helix angle, radians |
| $C_{l_\delta}$ | static aileron-effectiveness parameter $\left(\partial C_l/\partial\delta\right)$ |
| $(pb/2V)_\delta$ | rolling-effectiveness parameter $\left(\frac{\partial(pb/2V)}{\partial\delta}\right)$ |

Subscripts:

| | |
|---|---|
| $a_l$ | left aileron |
| $a_r$ | right aileron |

## MODEL AND APPARATUS

The model used in this investigation was a solid-steel swept wing of aspect ratio 3. The pertinent dimensions of the wing with the pylon-suspended tanks mounted on sweptforward pylon are shown in figure 1(a). The centrally mounted tip tanks are shown mounted on the wing in figure 1(b). The ailerons were true contour, constant chord, sealed gap, plain flaps. The ordinates of the airfoil section of the wing parallel to the plane of symmetry are given in table I.

The wooden tanks used in this investigation were bodies of revolution generated by revolving an NACA $64_1$-014 airfoil section, the ordinates of which are presented in table II.

The model is shown mounted on the free-to-roll sting in figure 2 and a schematic drawing of the sting arrangement is shown in figure 3. The free-to-roll sting is designed so that the model can roll freely under the action of its own ailerons. It can also be locked so that the rolling moments produced by the ailerons can be measured on the balance system.

The rate of roll is measured electrically and recorded on a paper tape over an extended period of time so as to minimize any error due to slight fluctuations in the rate of roll.

A more complete description of the apparatus and testing technique is given in reference 3.

## TESTS AND PROCEDURE

### Scope

The model was tested through a Mach number range from about 0.40 to 0.91 and for several aileron deflections from $0^{\circ}$ to $9.4^{\circ}$. Only the left aileron was deflected; the right aileron remained at zero deflection during all tests. All configurations except the centrally mounted tanks without fairing were tested through an angle-of-attack range from $0.3^{\circ}$ to $6.5^{\circ}$. The excepted configuration was tested at $0.3^{\circ}$ angle of attack only.

The variation of test Reynolds number with Mach numbers for average test conditions is presented in figure 4.

The tunnel-choking Mach number with this size model was estimated to be about 0.94 and the data are believed to be reliable up to a corrected Mach number of about 0.91.

### Corrections

A small tare correction accounting for bearing friction was determined by forced rotation of the rolling apparatus, under both vertical and horizontal loads, for the range of angular velocities encountered in the tests. This correction has been applied to the results in the form of an increment of damping-in-roll coefficient equal to a value of $C_{l_p} = 0.005$.

The rolling moment and Mach numbers have been corrected for blocking by the model and its wake by the method of reference 4. The jet-boundary effects were estimated and found to be negligible.

## Reduction of Data

The coefficient of damping in roll $C_{l_p}$ is defined as follows:

$$C_{l_p} = \frac{\partial C_l}{\partial pb/2V}$$

$$= -\frac{C_{l_\delta}}{(pb/2V)_\delta}$$

where the expressions $C_{l_\delta}$ and $(pb/2V)_\delta$ were evaluated graphically as the slopes of the curves of rolling-moment coefficient $C_l$ plotted against aileron deflection $\delta$ (determined from static tests) and of the nondimensional steady rate of rolling $(pb/2V)$ plotted against aileron deflection $\delta$ (determined from free-roll tests), respectively.

## RESULTS AND DISCUSSION

The results of the investigation are presented as follows:

| | Figure |
|---|---|
| Basic force data, $C_l$ plotted against $M$: | |
| Pylon-suspended tanks . . . . . . . . . . . . . . . . . . . . . . . | 5 |
| Centrally mounted tip tanks (faired) . . . . . . . . . . . . . . . | 6 |
| Centrally mounted tip tanks (without fairing) . . . . . . . . . . | 7 |
| Basic rolling data, $pb/2V$ plotted against $M$: | |
| Pylon-suspended tanks . . . . . . . . . . . . . . . . . . . . . . . | 8 |
| Centrally mounted tip tanks (faired) . . . . . . . . . . . . . . . | 9 |
| Centrally mounted tip tanks (without fairing) . . . . . . . . . . | 10 |
| Summary data, $C_{l_p}$, $C_{l_\delta}$, and $(pb/2V)_\delta$ plotted against $M$: | |
| Pylon-suspended tanks . . . . . . . . . . . . . . . . . . . . . . . | 11 |
| Centrally mounted tip tanks (faired) . . . . . . . . . . . . . . . | 12 |
| Comparison of configurations . . . . . . . . . . . . . . . . . . . | 13 |

Compared to the wing-alone characteristics (fig. 13) the pylon-suspended tanks had practically no effect on the static aileron-effectiveness parameter $C_{l_\delta}$ and caused only a slight increase in the damping-in-roll parameter $C_{l_p}$. This slight increase in the damping-in-roll coefficient $C_{l_p}$ can probably be attributed to the end-plate effect produced by the pylon which is swept forward from about midchord of the tip and would therefore be expected to have more effect on $C_{l_p}$ than on the aileron-effectiveness parameter $C_{l_\delta}$. The variation in the rolling characteristics with angle of attack for the wing with the pylon-suspended tanks attached (fig. 11) is small and very similar to the variation of these parameters for the wing alone (reference 3).

The centrally mounted tip tanks produced appreciable increases in both $C_{l_\delta}$ and $C_{l_p}$ (fig. 13). These effects are probably also attributable to the end-plate effect of the tank; however, because the tank extends along the full chord of the wing tip, in this case it would be expected to affect both $C_{l_p}$ and $C_{l_\delta}$. This effect is greatly dependent on the fairing as evidenced by the fact that $C_{l_p}$ and $C_{l_\delta}$ were affected almost as much by the addition of the fairing as by the addition of the tanks themselves (fig. 13).

It is interesting to note that for the particular wing-aileron configuration investigated the effects of the various tank configurations on $C_{l_p}$ and $C_{l_\delta}$ were such as to produce small and almost identical decreases in the rolling parameter $(pb/2V)_\delta$.

The characteristics of the centrally mounted tip-tank configuration are more sensitive to angle-of-attack changes (fig. 12) than the pylon-suspended configuration (fig. 11), although within the test range investigated, these effects are not of too great a magnitude.

Within the range of these tests, the increase in $C_{l_p}$ with Mach number for the various tank configurations at 0.3° angle of attack is similar but somewhat greater than the increase for the wing alone (fig. 13). The variation of $C_{l_\delta}$ with Mach number for these configurations is practically negligible.

## CONCLUSIONS

Based on tests to determine the effect of several tip-tank configurations on the rolling characteristics of a sweptback wing at high subsonic Mach numbers the following conclusions are indicated:

1. The pylon-suspended tank configuration had a negligible effect on the aileron-effectiveness parameter $C_{l_\delta}$ and slightly increased the magnitude on the damping-in-roll parameter $C_{l_p}$ in the Mach number range from about 0.40 to 0.91.

2. The centrally mounted tip tanks caused a fairly large increase in the aileron-effectiveness parameter $C_{l_\delta}$ and an even larger increase in damping-in-roll parameter $C_{l_p}$, particularly at the higher Mach numbers.

3. The addition of the fairing used between the centrally mounted tip tank and the wing was found to produce increases in the aileron-effectiveness parameter $C_{l_\delta}$ and the damping-in-roll parameter $C_{l_p}$ as great as those caused by the addition of the tank itself.

4. For the particular wing-aileron configuration used in this investigation the effects of the various tank configurations on the damping-in-roll parameter $C_{l_p}$ and the aileron-effectiveness parameter $C_{l_\delta}$ were such as to produce small and almost identical decreases in the rolling parameter $(pb/2V)_\delta$.

5. Within the range of these tests, the increase in $C_{l_p}$ with Mach number for the various tank configurations at 0.3° angle of attack is similar but somewhat greater than the increase for the wing alone. The variation of $C_{l_\delta}$ with Mach number for these configurations is practically negligible.

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## REFERENCES

1. Murray, Harry E., and Wells, Evalyn G.: Wind-Tunnel Investigation of the Effect of Wing-Tip Fuel Tanks on Characteristics of Unswept Wings in Steady Roll. NACA TN 1317, 1947.

2. Silvers, H. Norman, and Spreemann, Kenneth P.: Experimental Investigation of Various External-Store Configurations on a Model of a Tailless Airplane with a Sweptback Wing. NACA RM L9K25, 1949.

3. Myers, Boyd C., II, and Kuhn, Richard E.: High-Subsonic Damping-in-Roll Characteristics of a Wing with the Quarter-Chord Line Swept Back 35° and with Aspect Ratio 3 and Taper Ratio 0.6. NACA RM L9C23, 1949.

4. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA RM A7B28, 1947.

TABLE I

COORDINATES OF SYMMETRICAL AIRFOIL SECTION OF WING

[All dimensions in percent of wing chord parallel to plane of symmetry of wing]

| Station, x | Ordinate, ±y |
|---|---|
| 0 | 0 |
| .5871 | 1.0958 |
| .8803 | 1.3226 |
| 1.4661 | 1.6687 |
| 2.9264 | 2.2597 |
| 5.8297 | 2.9981 |
| 8.7103 | 3.4923 |
| 11.5680 | 3.8626 |
| 17.2154 | 4.3929 |
| 22.7728 | 4.7516 |
| 28.2409 | 4.9951 |
| 33.6203 | 5.1488 |
| 38.9118 | 5.2322 |
| 44.1160 | 5.2200 |
| 49.2336 | 5.1300 |
| 54.2654 | 4.9088 |
| 59.2118 | 4.5506 |
| 64.0736 | 4.0784 |
| 68.9587 | 3.5320 |
| 73.5461 | 2.9550 |
| 78.1583 | 2.3821 |
| 82.6881 | 1.8395 |
| 87.1366 | 1.3383 |
| 91.5043 | .8757 |
| 95.7921 | .4408 |
| 100.0000 | .0206 |

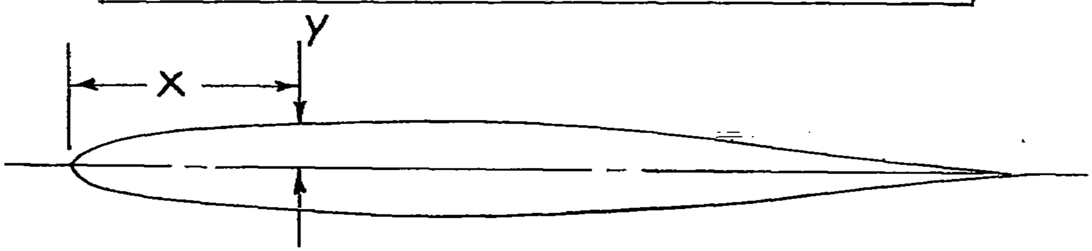


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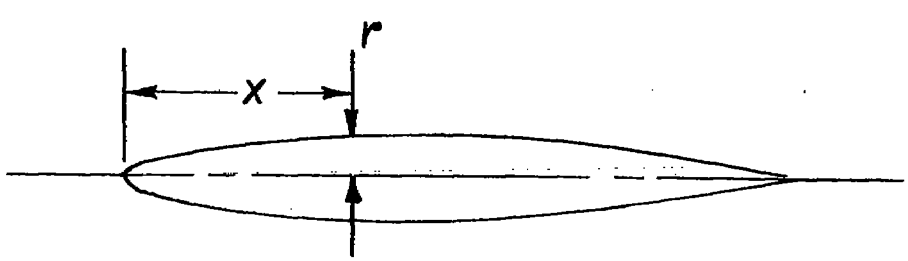
TABLE II

COORDINATES OF TANK

[The tank was generated by revolution of NACA $64_1$-014 airfoil section about X-axis]

| Station, x (in.) | Radius, r (in.) |
|---|---|
| 0 | 0 |
| .070 | .148 |
| .105 | .177 |
| .175 | .222 |
| .350 | .295 |
| .700 | .407 |
| 1.050 | .496 |
| 1.400 | .571 |
| 2.100 | .692 |
| 2.800 | .784 |
| 3.500 | .855 |
| 4.200 | .910 |
| 4.900 | .947 |
| 5.600 | .972 |
| 6.300 | .980 |
| 7.000 | .974 |
| 8.400 | .912 |
| 9.800 | .737 |
| 11.200 | .481 |
| 12.600 | .202 |
| 13.300 | .077 |
| 14.000 | 0 |
| L.E. radius: 0.1554 | |



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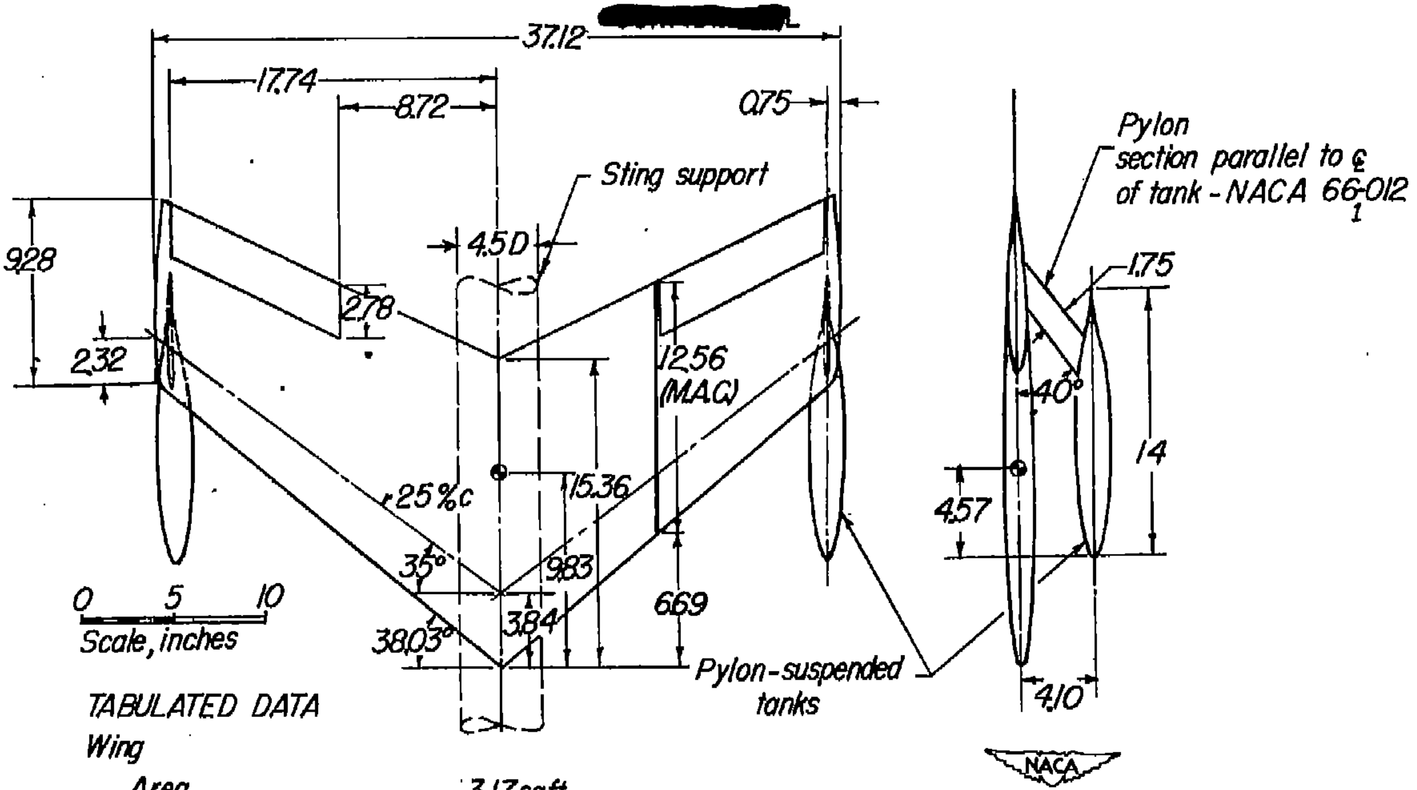



TABULATED DATA

Wing

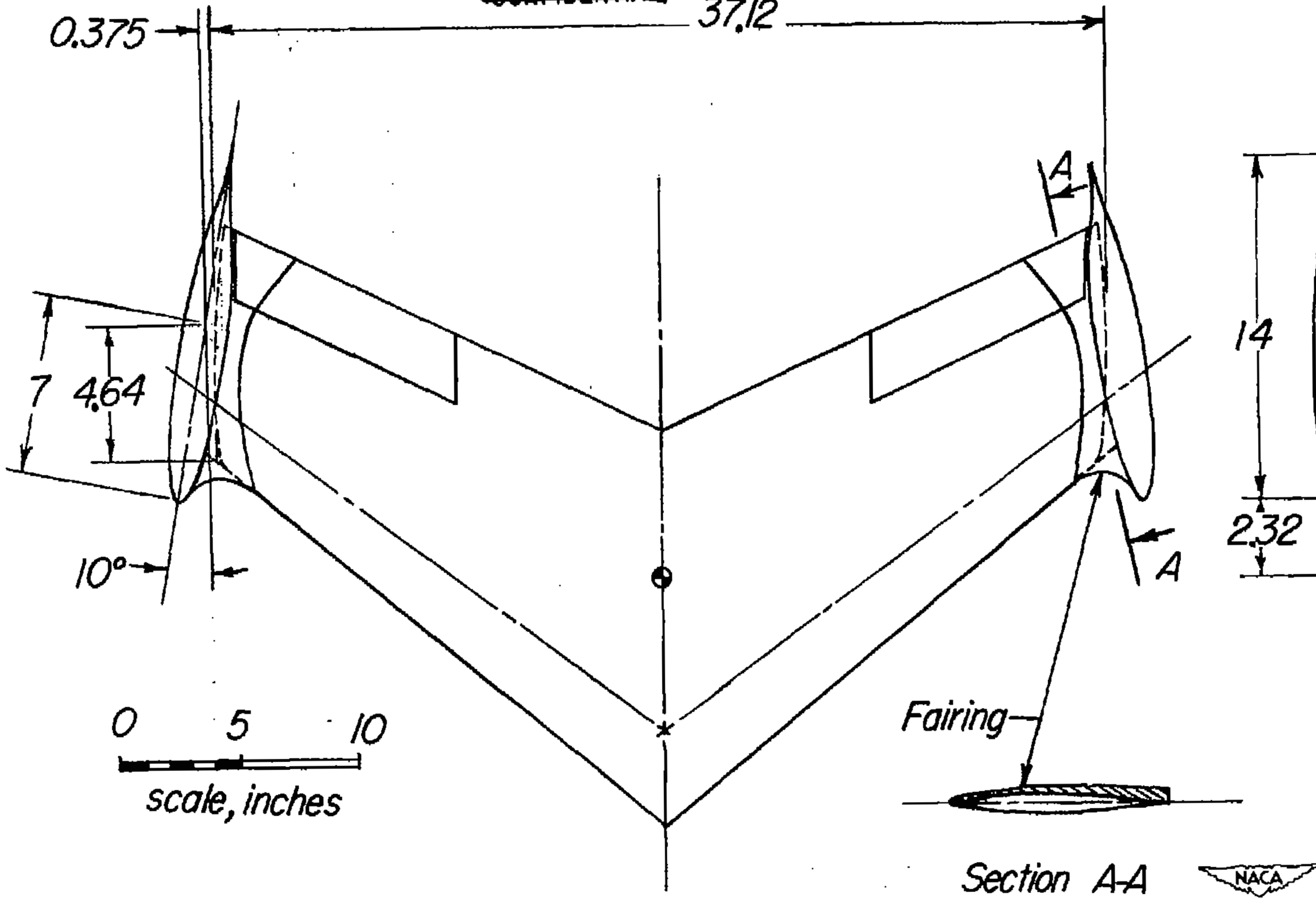
| | |
|---|---|
| Area | 3.17 sq.ft. |
| Aspect ratio | 3.0 |
| Mean aerodynamic chord | 1.05 ft |
| Dihedral | 0° |
| Airfoil (Table I) | Symmetrical |
| Max. thickness | 0.105c |
| Location of max. thickness | 0.39c |

[redacted]

(a) Pylon-suspended tank configuration.

Figure 1.- The test wing and tank configurations.

[redacted]

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(b) Centrally mounted tip-tank configuration (faired).

Figure 1.- Concluded.

[redacted]

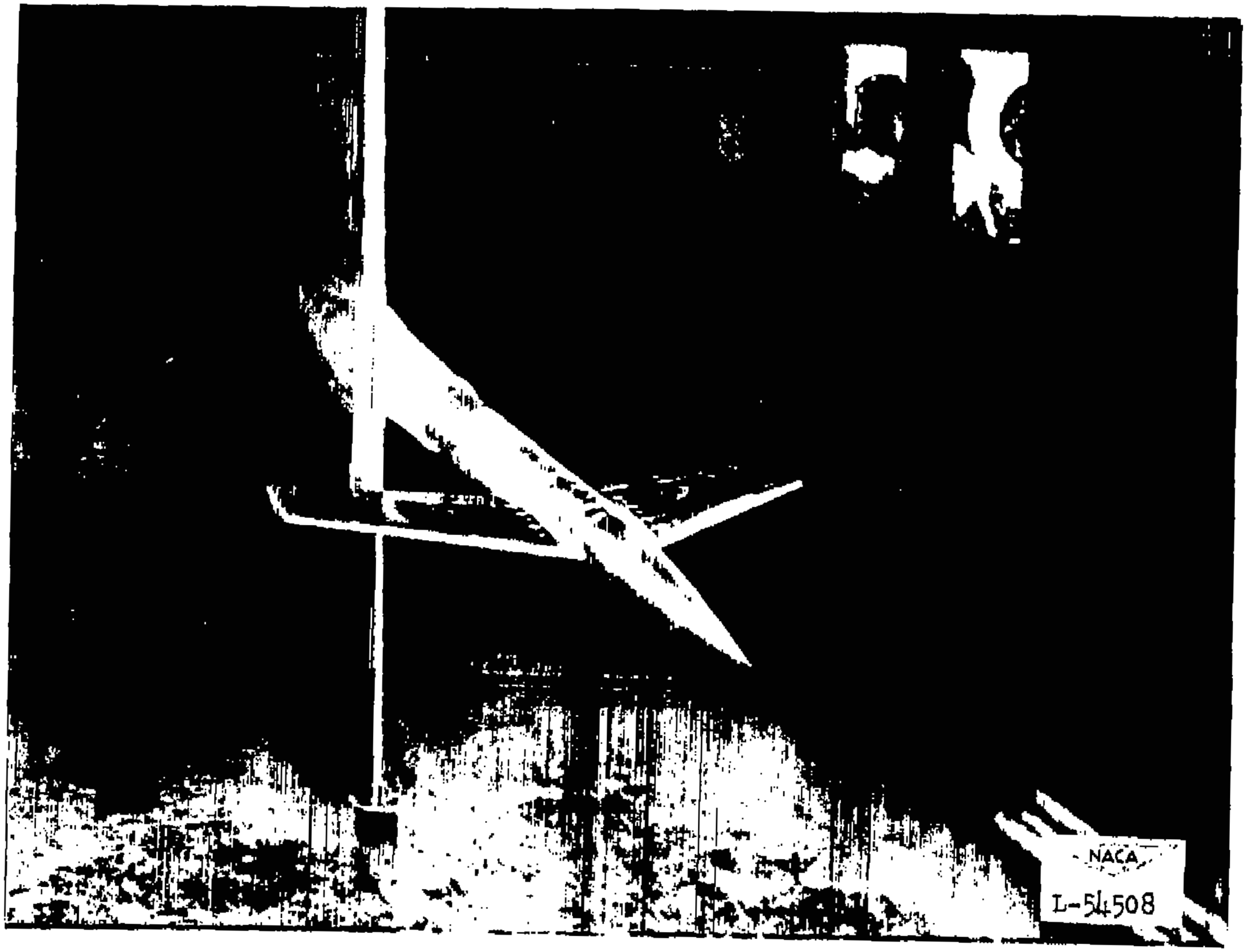



Figure 2.- Test wing, tanks off, mounted on the free-roll sting in the Langley high-speed 7- by 10-foot tunnel.

[redacted]

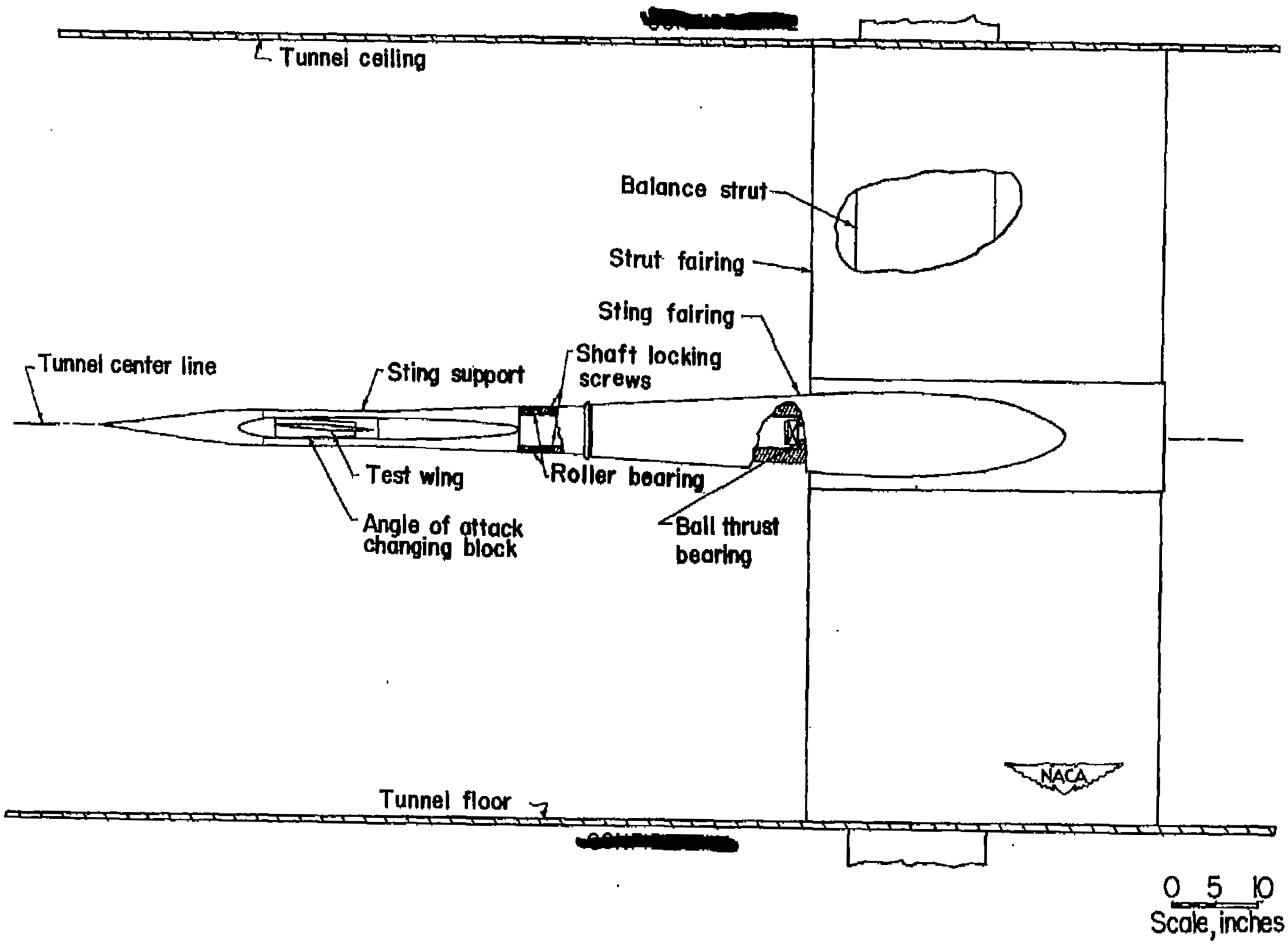



Figure 3.- Schematic drawing of the free-rolling sting mounted in the Langley high-speed 7- by 10-foot tunnel test section.

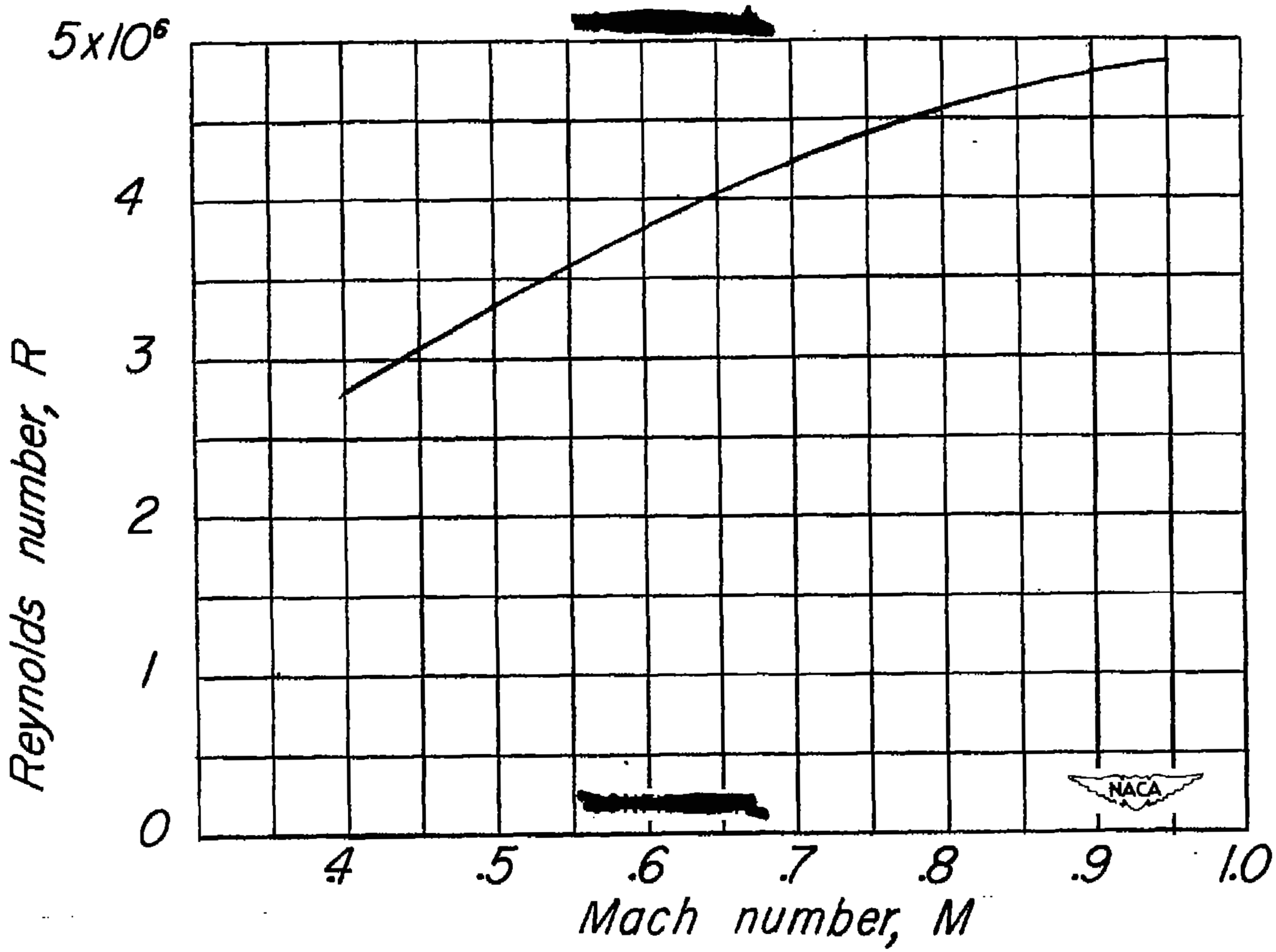



Figure 4.- Variation of test Reynolds number with Mach numbers based on the mean aerodynamic chord of 1.05 feet.

[redacted]

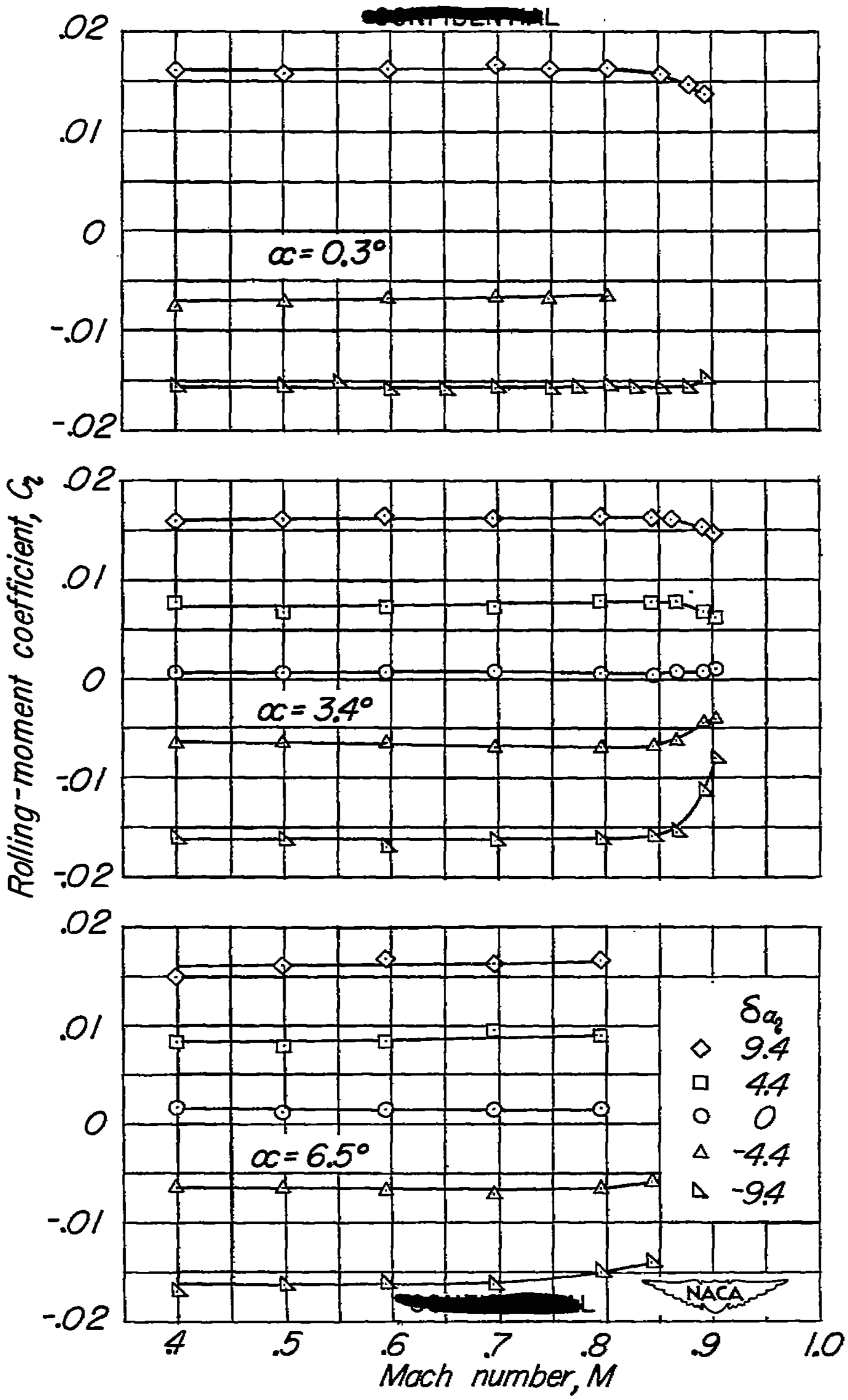



Figure 5.- Variation with Mach number of the rolling-moment characteristics of the pylon-suspended tank configuration; $\delta_{a_r} = 0^{\circ}$.

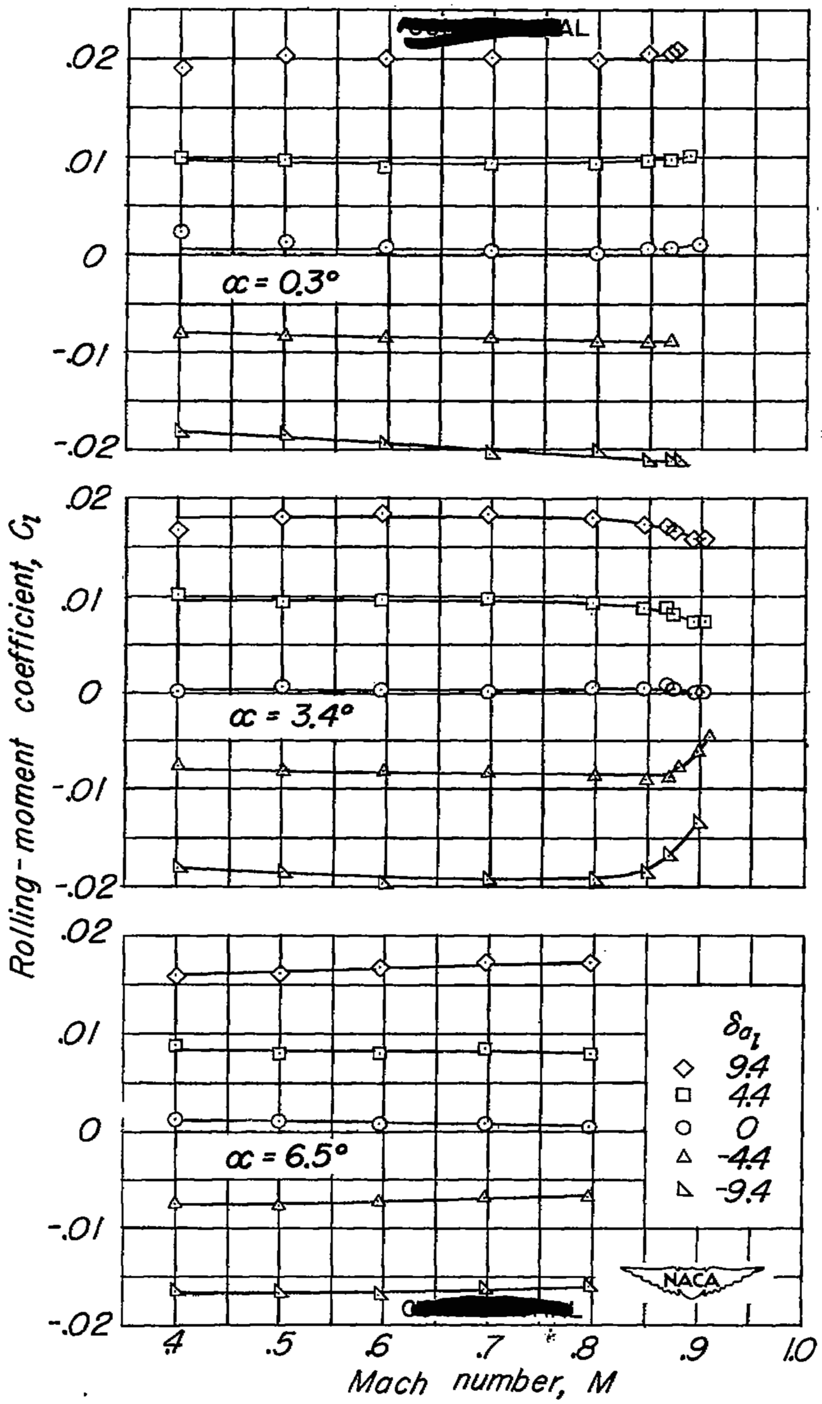
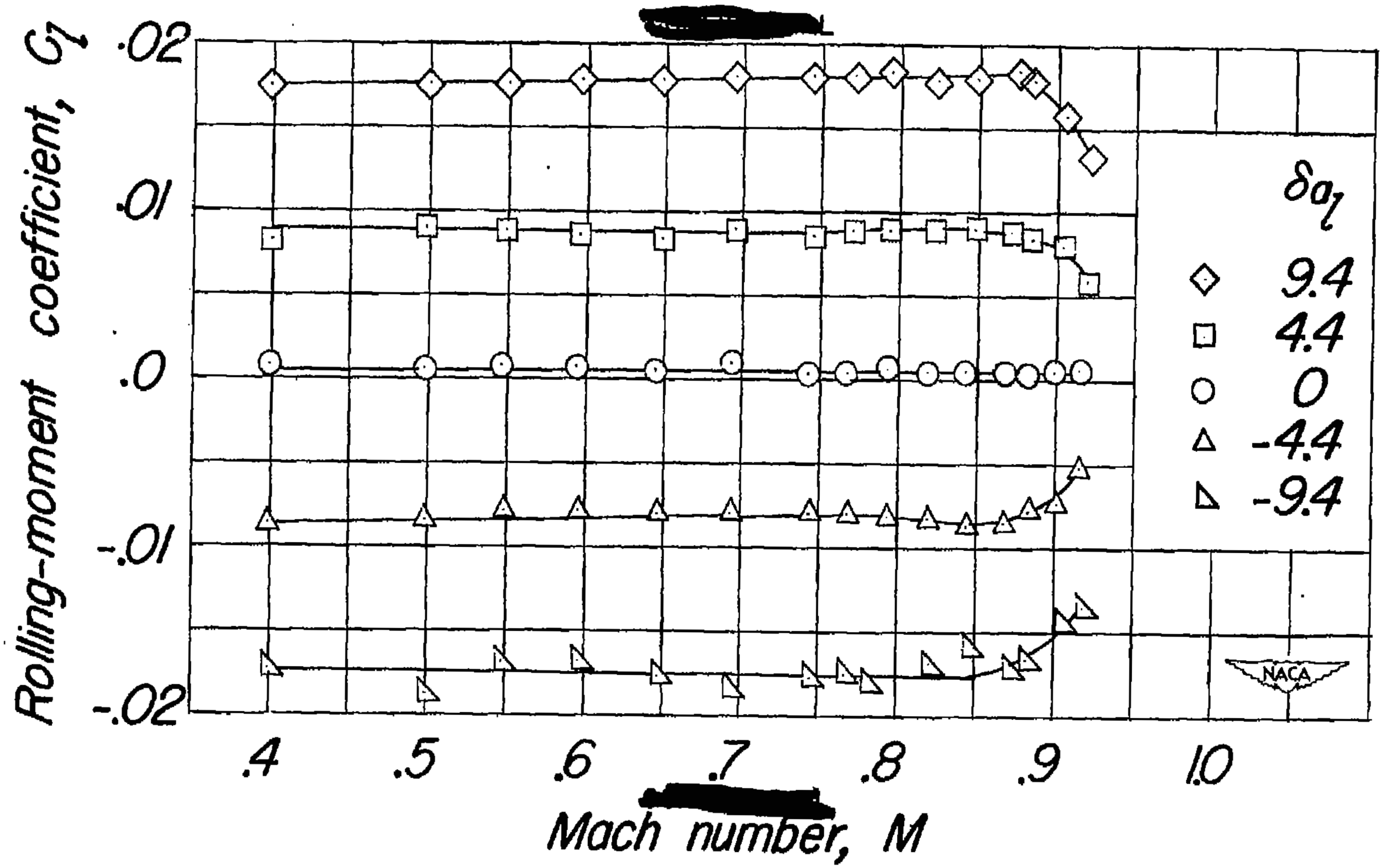



Figure 6.- Variation with Mach number of the rolling-moment characteristics of the centrally mounted tip-tank configuration (faired); $\delta_{a_r} = 0^\circ$.

[redacted]




[redacted]

Figure 7.- Variation with Mach number of the rolling-moment characteristics of the centrally mounted tip-tank configuration (without fairing); $\alpha = 0.3^{\circ}$; $\delta_{a_r} = 0^{\circ}$.

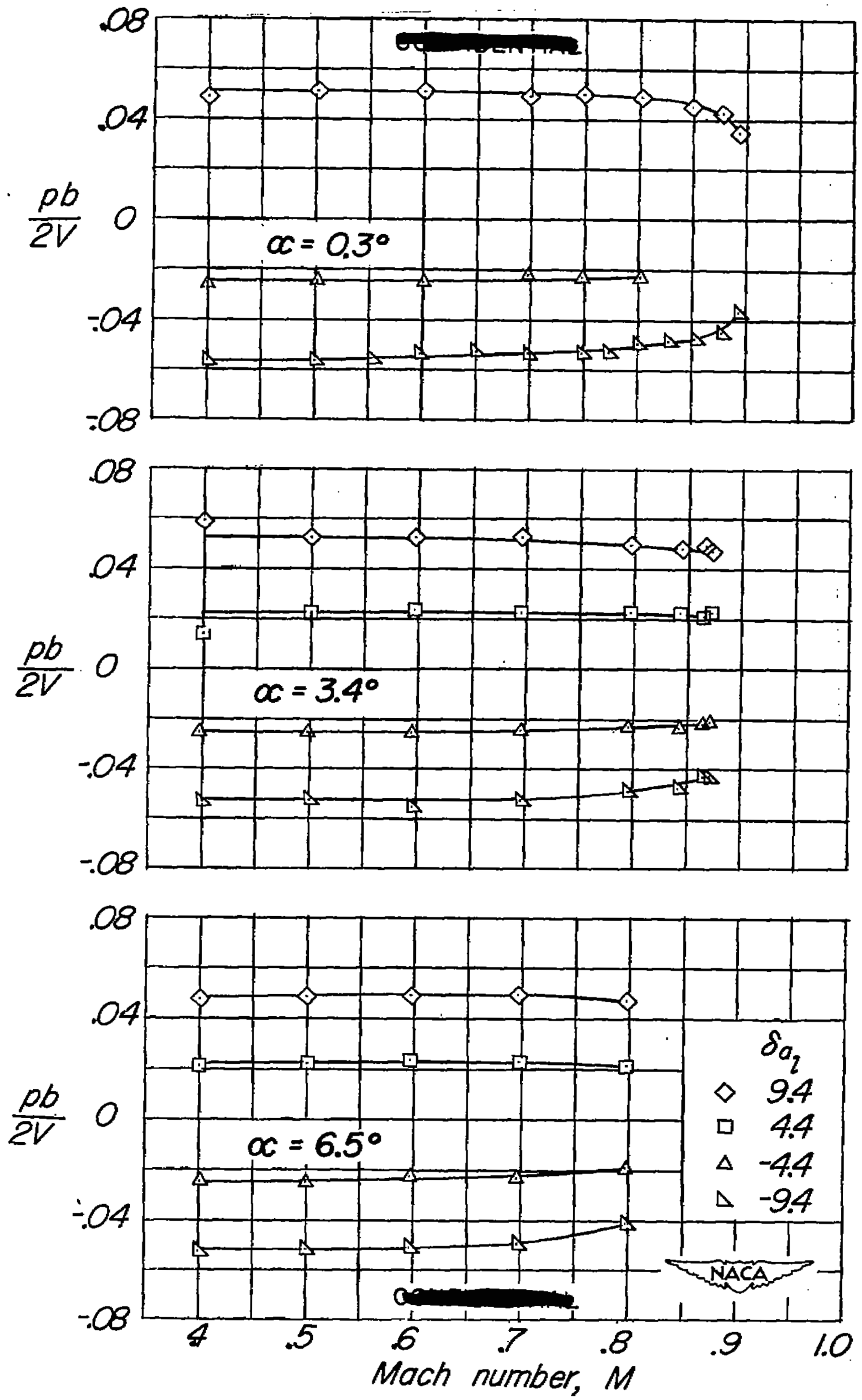



Figure 8.- Effect of Mach number on the wing-tip helix angle obtained with the pylon-suspended tank configuration; $\delta_{a_r} = 0^{\circ}$.

[redacted]

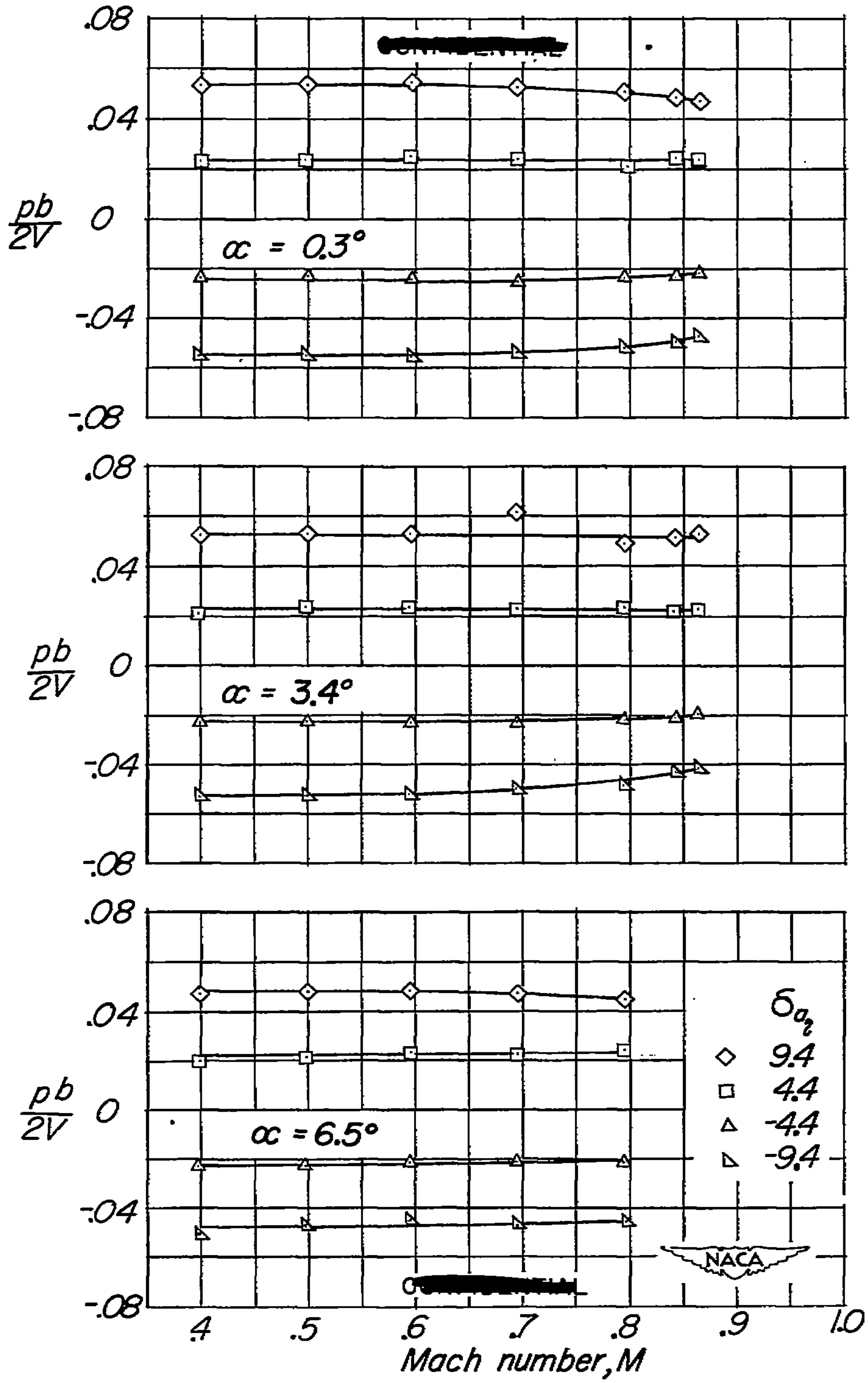



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Figure 9.- Effect of Mach number on the wing-tip helix angle obtained with the centrally mounted tip-tank configuration (faired); $\delta_{a_r} = 0^\circ$.

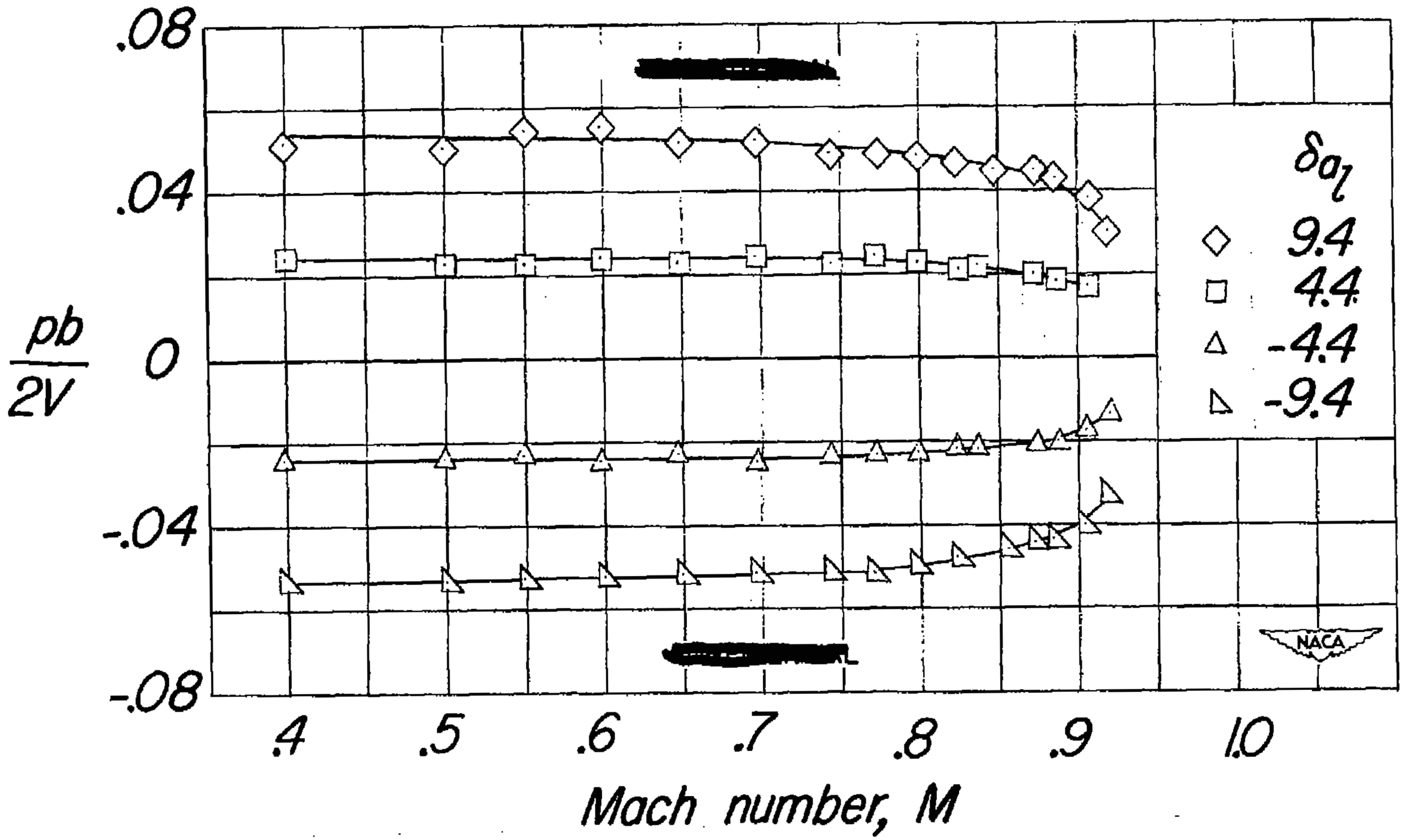



Figure 10.- Effect of Mach number on the wing-tip helix angle obtained with the centrally mounted tip-tank configuration (without fairing); $\alpha = 0.3^{\circ}$; $\delta_{a_r} = 0^{\circ}$.

[redacted]

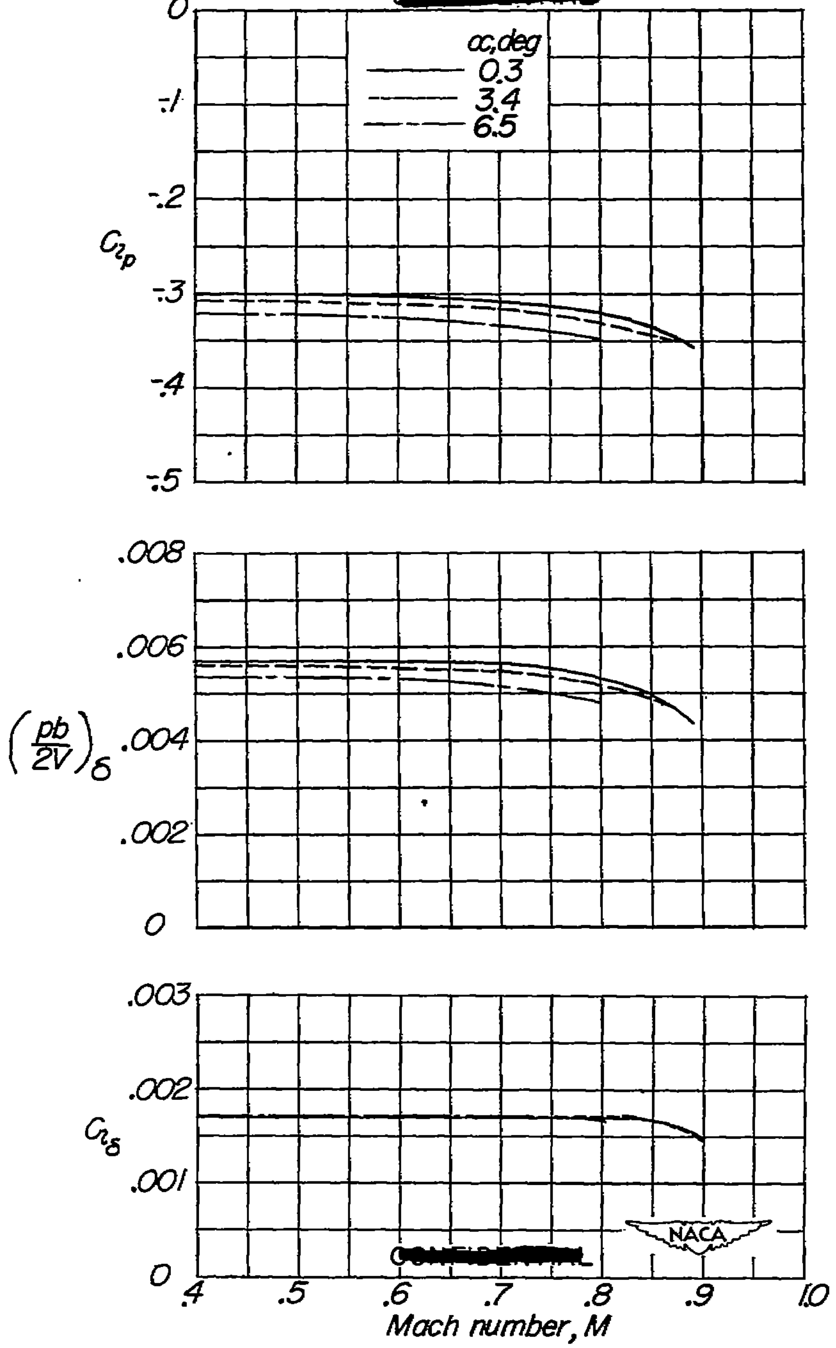



Figure 11.- Variation with Mach number of the parameters $C_{l_p}$, $C_{l_\delta}$, and $\left(\frac{pb}{2V}\right)_\delta$ at several angles of attack for the pylon-suspended tank configuration.

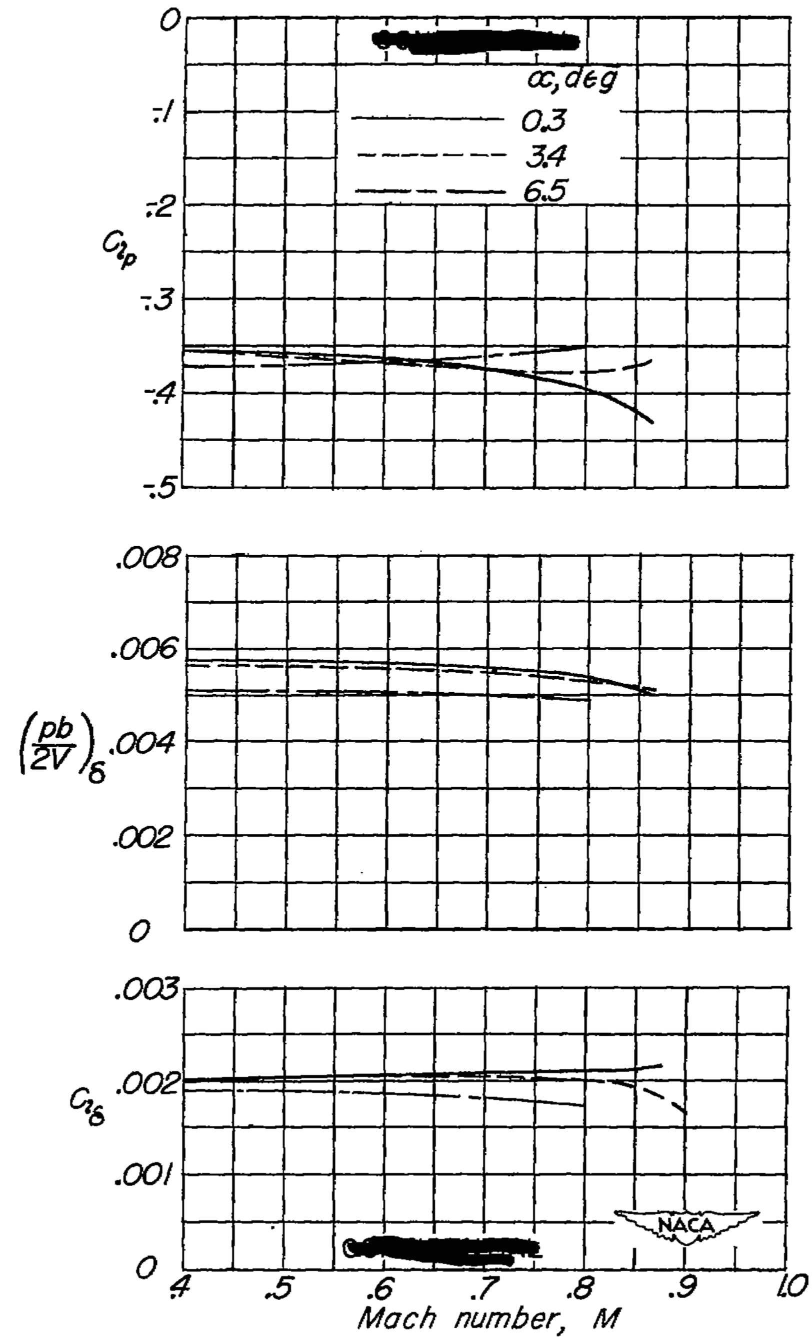
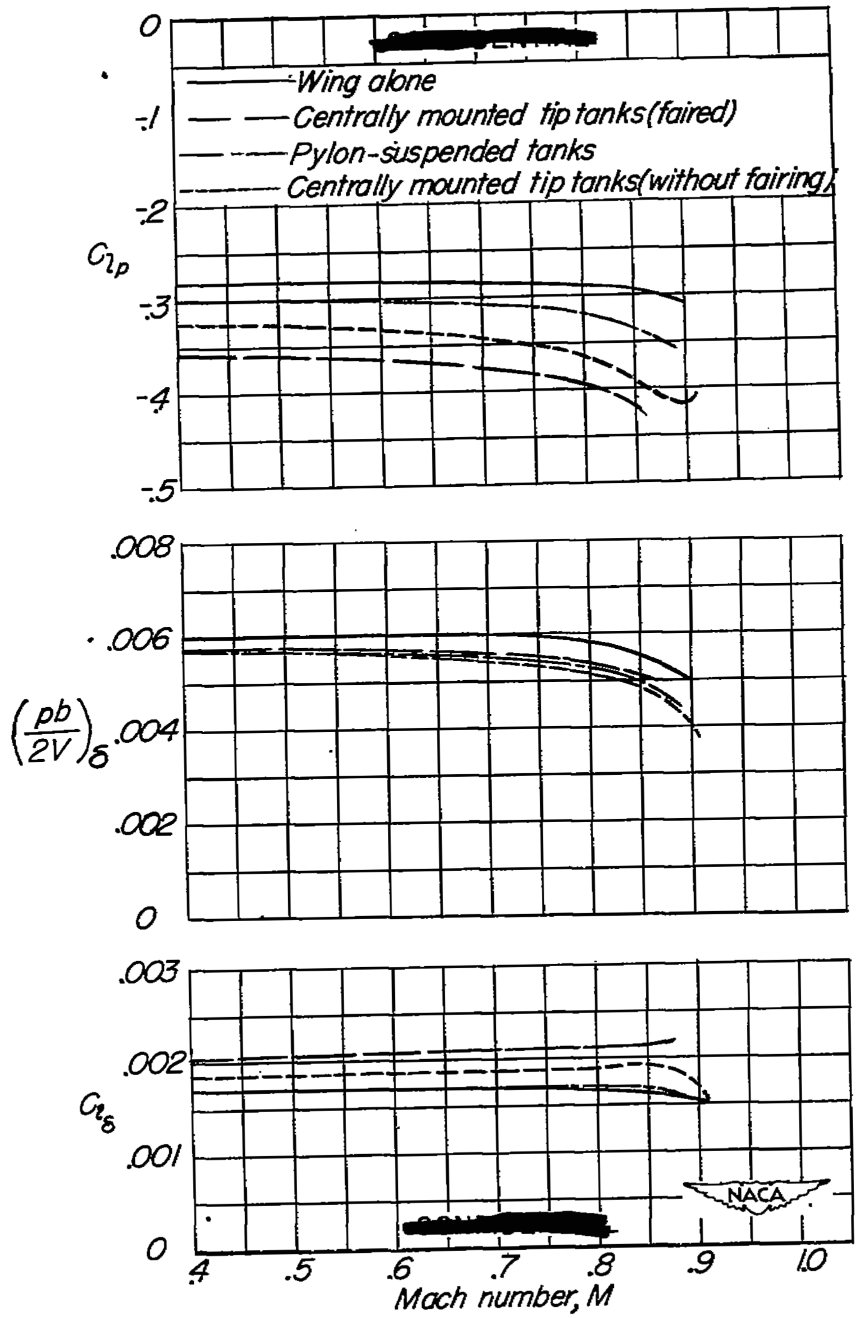
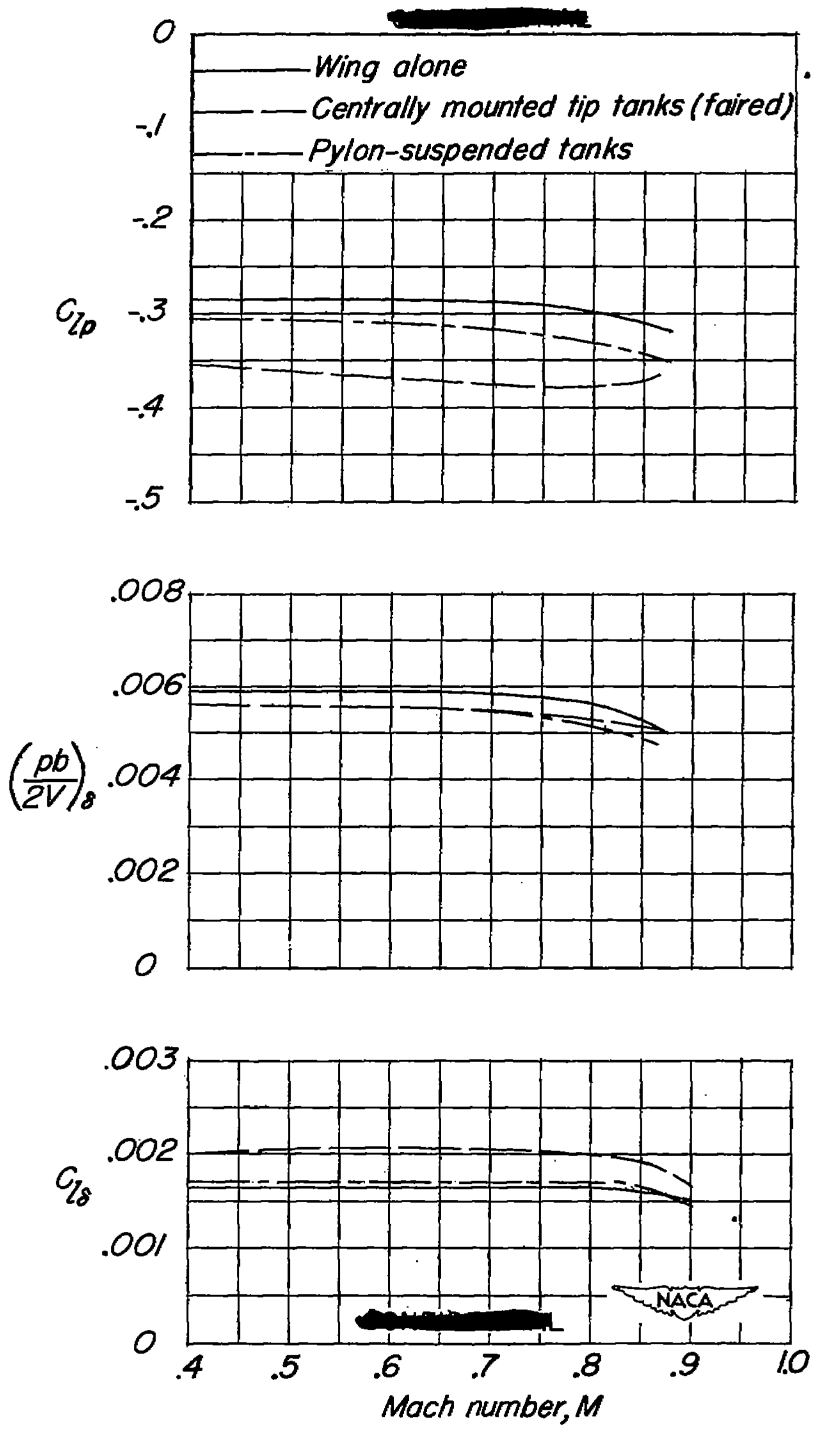



Figure 12.- Variation with Mach number of the parameters $C_{l_p}$, $C_{l_\delta}$, and $\left(\frac{pb}{2V}\right)_\delta$ at several angles of attack for the centrally mounted tip-tank configuration (faired).



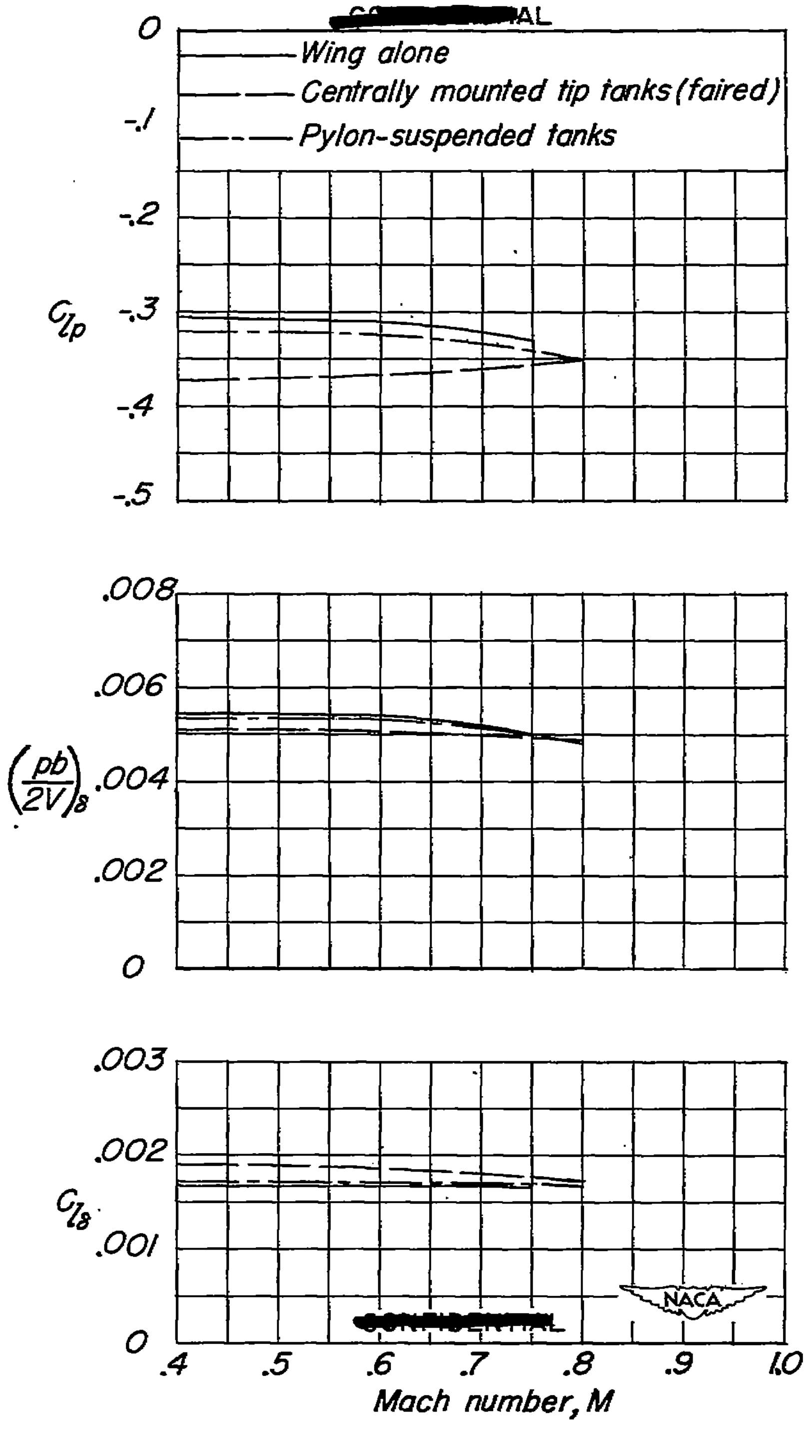

(a) $\alpha = 0.3^\circ$.

Figure 13.- Comparison of the effect of the various configurations on the parameters $C_{l_p}$, $C_{l_\delta}$, and $\left(\frac{pb}{2V}\right)_\delta$.




(b) $\alpha = 3.4^\circ$.

Figure 13.- Continued.




(c) $\alpha = 6.5^{\circ}$.

Figure 13.- Concluded.

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